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Second-generation bioethanol as a sustainable energy source in Malaysia transportation sector: Status, potential and future prospects

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ABSTRACT

The energy crisis has become a crucial issue. The rapid depletion of the fossil fuels has driven the world to utilize renewable energy (RE) sources. To develop RE industries, the Malaysian government has been continuously reviewing its energy policy and undertaking intensive efforts to ensure long-term reliability in the energy supply. The most attractive and practical choice to replace fossil fuels as the main energy source is biofuels, which are mostly in liquid form. In Malaysia, the transportation sector has become the main driver for increasing the liquid fuel demand. This study outlines the importance of second-generation bioethanol as a potential energy source for the Malaysia transportation sector and its future development perspectives. In this work, it is shown that Malaysia has consistently promoted the RE industry in its energy policy, over non-renewable conventional energy resources with their negative impact to the environment. In Malaysia, which has a significant amount of agricultural activities, agricultural wastes have become a very promising alternative source for second-generation bioethanol (SGB) production. It is estimated that the biomass availability and its potential energy generated are 50,919 dry kton/year and 13,343 kton/year, respectively. The estimated energy generated from biomass can contribute approximately 21.5% of the national energy requirement. In addition, the key drivers for Malaysia to move towards sustainable energy sources, such as SGB, are discussed. SGB can contribute to energy security and help to reduce CO_2 emissions in Malaysia. SGB is also economically feasible. Furthermore, the Malaysian market for bioethanol is potentially much larger than the market for biodiesel, because a much larger portion of the vehicle fleet runs on gasoline. Hence, implementing and promoting second-generation bioethanol effectively is definitely a strategic move for Malaysia to become a self-sufficient country in the future.

Contents

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1. Introduction

In the mid and late 1800s, crude oil was largely discovered and supplied by the United States, from areas such as Pennsylvania and Texas. This expansion in supply allowed petroleum-based fuels to become inexpensive, and thus, fossil fuels were one of the primary drivers of the industrial age, especially for the production of power to run factories and automobiles [1]. However, the world oil crisis of the 1970s highlighted concerns over the scarcity of resources. The rapid depletion of the fossil fuel reserve, as well as climate change and the over-dependence on oil, has driven the world to renewable energy sources, which are abundant, untapped and environmentally friendly [2,3]. In particular, the recent development of renewable energy (RE) technologies and policies in Malaysia has promoted the expansion of biofuels production, which is believed to be one of the paths to achieving fuel security as transport has become the main driver for increasing liquid fuel demand.

Based on studies by the International Energy Agency (IEA), biofuels for transport represent a key source of diversification from petroleum [4]. Biofuels are solid, liquid or gaseous fuels that are predominantly produced from biorenewable or combustible renewable feedstocks. Liquid biofuels are the most vital, because they can replace petroleum fuels. Biofuels are non-polluting and obtained from renewable energy sources, while petroleum is a polluting fuel and obtained from non-renewable energy sources, such as fossil fuels [5]. The difference between biofuels and petroleum is their oxygen content. Biofuels have higher oxygen content than petroleum, which can improve combustion and reduce hydrocarbon, carbon monoxide and particulate emissions. The presence of higher oxygen content in biofuels increases its combustion efficiency. Thus, the combustion efficiency and octane number of biofuels are higher than those of gasoline [6,7]. Among the numerous types of renewable biofuels, second-generation bioethanol (SGB) is currently the most advanced environmentally friendly biofuel made from non-food crops. SGB is also a completely liquid fuel that can substitute for fossil fuels as transport fuel [5].

In Malaysia, the production and consumption of biofuel has been driven largely by the National Biofuel Policy, which was launched on August 10, 2005. This policy outlines a four-pronged strategy, as follows: (i) producing a bio-diesel fuel blend of 5% processed palm oil with 95% petroleum diesel; (ii) encouraging the use of biofuel among the public with incentives; (iii) establishing an industry standard for biodiesel quality, which will be the responsibility of Standard and Industrial Research Institute of Malaysia (SIRIM); and (iv) setting up a palm oil biodiesel plant, which is targeted to be built in Labu, Negri Sembilan. However, due to issues of market competency and taking into account the energy crisis and climate change, this policy has introduced a diversification of bioenergy, such as bioethanol. Currently, there is a very little ethanol production from biomass feedstocks in Malaysia, even though there may be a significant potential for the use of oil palm biomass [8,9]. According to the Asia Oceania Convention 2010, the Global Sustainable Bioenergy (GSB) Project has brought clarity and resolution to the present and future direction of energy generation, production of fine and specialty chemicals and the development of new and useful bioprocesses, all derived from biological origin or biomass, considering its sustainability and the promotion of economic development. This project has led the Malaysian government to acknowledge the importance of bioenergy as well as other types of RE in shaping the future of the Malaysian economy and the world economy as a whole, especially given the declining rate at which the fossil fuel supply is meeting the world's energy demand. Recently, the focus on renewable biofuels in Malaysia is restricted to biodiesel and bioethanol only. Most liquid fuels in Malaysia are utilized in the transportation sector. Malaysia also intends to convert lignocellulosic biomass into SGB through biorefining. Bioethanol is carbon "neutral" and essentially free from sulfur and aromatics, which are harmful to living organisms. In addition, the complete combustion of bioethanol produces only carbon dioxide and water [10]. The development of environmentally friendly bioethanol will go a long way in protecting the next generation from the negative consequences of global warming.

The Malaysian market for bioethanol is potentially much larger than the market for biodiesel, because a much larger proportion of the vehicle fleet runs on gasoline. In a country that has a significant amount of agricultural activity, such as Malaysia, biomass can be a very promising alternative source of RE [11]. The ethanol derived from biomass, or second-generation bioethanol (SGB), offers greater promise in replacing fossil fuels than does bioethanol derived from edible sources, or first-generation bioethanol (FGB), because SGB does not compete with the human food supply [12]. To enable the sustainable production of SGB in Malaysia, various issues and measures need to be taken into account.

The objective of this study is to highlight the importance of SGB as a sustainable energy in the Malaysian transportation sector and its future perspectives. We will discuss the current energy and fuel profile in Malaysia. Subsequently, we will elaborate on the potential of the huge biomass feedstock in the Malaysian RE industry to promote the development of SGB. We will also discuss the key drivers for Malaysia to move towards sustainable energy sources, such as SGB.

2. Energy and fuel profile in Malaysia

Malaysia's first oil well was discovered by Shell on Canada Hill in Miri, Sarawak, in 1910. Shell built Malaysia's first oil refineries in Miri, Sarawak, and Port Dickson, Peninsular Malaysia, in 1914 and 1963, respectively. Malaysia holds a special place in the history of Shell worldwide, because it was in this region that the company first put its roots down. At the same time, the discovery of natural gas liquefaction in Sarawak represented a turning point for Shell. Today, Shell has become the petroleum retail market leader in Malaysia, catering to a third of Peninsular Malaysia's market requirements and half of Sabah and Sarawak's market requirements, especially in the transportation sector [13]. Nevertheless, the energy crises of 1973 and 1979 led the OPEC (Organization of Petroleum Exporting Countries) to cut exports. Consequently, non-OPEC member nations, such as Malaysia, experienced a very large decrease in their oil supply. These crises resulted in severe shortages and sharp increases in the prices of high demand oil-based products, most notably gasoline. These crises have in turn led to an increased interest in alternative fuel research on renewable energy (RE), such as second-generation bioethanol (SGB) [1]. To develop RE industries, such as SGB, the Malaysian government has been continuously reviewing its energy policy and undertaking intensive efforts to safeguard the supply of energy from both depletable and renewable resources [12]. As a result, the Malaysian government has formulated numerous energy and fuel-related policies,

such as the Petroleum Development Act (1974), the National Energy Policy (1979), the National Depletion Policy (1980), the Four Fuel Diversification Policy (1981, 1999) and the National Biofuel Policy (2006), to ensure the long-term reliability and security of the energy supply for sustainable social-economic development in the country [12,14–16]. Recently, PETRONAS, which is a national oil company of Malaysia and established under the Petroleum Development Act (1974), has supported the biofuel policy in Malaysia. For instance, in 2009, PETRONAS Dagangan Berhad marked its first biodiesel (B5) delivery to the Ministry of Defense (MINDEF) and Dewan Bandaraya Kuala Lumpur (DBKL), an initiative in support of the Malaysian Biofuel Industry Act 2007 [17].

The main sectors utilizing energy in Malaysia are the transportation and industrial sectors, which account for 40.3% and 38.6% of total usage, respectively. The remaining energy is supplied to the residential and commercial sectors (13%), the agriculture sector (0.3%) and others (7.8%). Future energy demand is expected to grow at a rate of 5–7% annually for the next 20 years from 2004. Thus, Malaysia will build more coal-fired plants to reduce the overdependence on any single source of energy, such as coal, oil and natural gas, for energy generation. The fuel mix is generated based on 50–55% from natural gas, 30–35% from coal and 20–10% from hydroelectric, oil and renewable energy (RE) [15]. However, mixing energy from conventional non-renewable energy sources, such as fossil fuels (oil, coal and natural gas), with that from renewable energy sources has two major disadvantages. First, the use of non-renewable energy sources depletes to a finite resource. Second, the combustion of non-renewable energy sources causes the emission of greenhouse gases and contributes to climate change. To ensure the socio-economic development in Malaysia and meet the commitment to the UN convention on Climate Change and Kyoto Protocol, Malaysia has been taking steps to reduce the usage of non-renewable energy [14]. For instance, the use of SGB as the main transport fuel has a number of environmental advantages and reduces domestic carbon monoxide, carbon dioxide and volatile organic compound emissions, as it is a carbon-neutral fuel [1].

Given the energy challenges, the increases in energy demand in Malaysia, and the disadvantages of non-renewable conventional energy resources, especially their negative impact towards the environment, the Malaysian government introduced the Eight Malaysian Plan (2001–2005) to further diversify the energy mix with more sources of alternative energy. Under this plan, the Five Fuel Diversification Strategy was implemented with the addition of the renewable energy (RE) as the fifth source of fuel in the energy supply. The objective was for RE to contribute 5% of the electricity supply of the country by the year 2005 [14]. This contribution was estimated to save the country RM5 billion (US$1.32 billion) over a period of 5 years [12]. According to this policy, a Small Renewable Energy Power Program (SREP) was launched under the Special Committee on Renewable Energy (SCORE), which is under the Ministry of Energy, Water and Communication (MEWC). The purpose was to encourage the utilization of renewable resources, such as biomass, municipal waste, biogas, solar and mini-hydro, for energy generation. Biomass is the most important renewable source in Malaysia as Malaysia produces a huge amount of agriculture waste every year [12,15,18]. The biomass resources that are available in Malaysia are palm oil residues, wood residues and rice husks. This biomass can be used in heat and electrical generation (co-generation) or converted into fuels such as bioethanol. However, the target of having 5% RE in the energy supply mix by 2005 was not achieved successfully. The main obstacle is Malaysia's lack of a policy framework and financial mechanism [15].

In 2006, the Ninth Malaysia Plan (2006–2010) was introduced to strengthen the initiatives for energy efficiency. However, despite rigorous initiatives, the renewable energy targets set out under the Ninth Malaysia Plan period were not achieved. Therefore, the Prime Minister of Malaysia, Dato' Sri Mohd *Najib, introduced a New Energy Policy in the Tenth Malaysia Plan (2011–2015).* This Energy Policy (2011–2015) emphasizes that the energy supply will continue to be strengthened by creating a more competitive market and reducing energy subsidy in stages. Under *Tenth Malaysia Plan,* several new initiatives anchored upon the Renewable Energy Policy and Action Plan will be undertaken to achieve a renewable energy target of 985 MW by 2015, contributing 5.5% to Malaysia's total electricity generation mix. Fig. 1 shows the increase in renewable energy (RE) from <1% in 2009 to 5.5% of Malaysia's total electricity generated by 2015. According to Fig. 1, the major utilization of biomass in RE industries have shown its potential in replacing fossil fuels as energy sources in the next 5 years for generating power and fuels such as SGB [19]. With this target in mind, a reduction of 70 million tons of CO_2 will be achieved over a 20-year period [15]. In addition, new alternative fuels will be generated over the next few decades.

In the 2010 Malaysia Budget, the government announced several measures to further promote the use of green technologies. These measures included restructuring the Malaysia Energy Center as the Malaysia Green Technology Corporation (GreenTech Malaysia), organizing the International GreenTech and Eco Products Exhibition and Conference Malaysia (IGEM) from 14-17 October 2010 for green technology companies to showcase their products in Malaysia, introducing initiatives to protect the

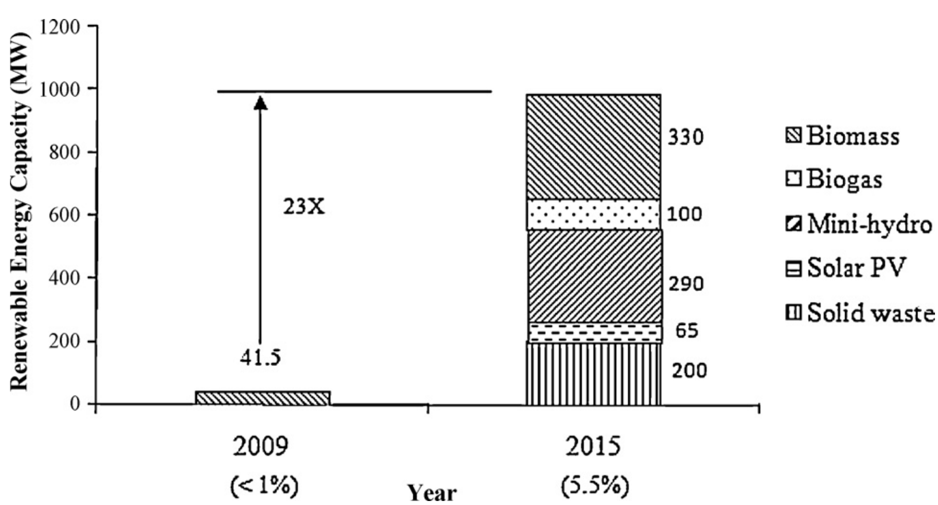


Fig. 1. Renewable energy (RE) will increase from <1% in 2009 to 5.5% of Malaysia's total electricity generated by 2015 [20,21].

environment and introducing the feed-in tariff (FiT) to support the development of renewable energy. In 16 October 2010, the Malaysia Budget 2011 was announced. This budget will promote the National Green Technology Policy. The key areas of focus for this policy are energy, building, water and waste management as well as transportation. As the Malaysian automotive sector is the largest transportation sector, this policy will look at the incorporation of green technologies in transportation infrastructure and vehicles, and in particular, biofuels and public road transport [22]. These initiatives indicate that Malaysia is constantly sustaining our living environment by promoting the utilization of green energy sources.

3. Renewable energy in Malaysia

To ensure that the development of energy resources will continue to contribute to the nation's economic growth and well-being, attention is increasingly directed towards the sustainable development of depletable resources as well as the continued diversification of energy resources, especially renewable energy [23]. Renewable energies are essential components in the global energy portfolio because they contribute to world energy supply security, reduce dependence on fossil fuel resources, and provide opportunities for mitigating greenhouse emissions [24].

Renewable energy plays an important role in Malaysia. In 1993, the contribution of renewable energy to the overall energy demand of the country was about 12% [23]. Thus, efforts are being made to actively promote and increase the utilization of renewable energy resources. Under the Small Renewable Energy Programme (SREP), two projects with a combined capacity of 12 MW were officially implemented in the 2000–2005 period: the UNDP/GEF assisted Biomass Power Generation and Cogeneration in Palm Oil Mills (BIOGEN) and the Malaysia Building Integrated Photovoltaic Technology Application Project (MBIPV) [25]. The MBIPV project, which is a national project under the Ministry of Energy, Green Technology and Water, promotes the use to photovoltaic (PV) technology to tap into solar energy and generate electricity for buildings. According to the Malaysia Budget 2011, the government plans to promote the solar energy sector. However, Malaysia presently faces some constraints and challenges in the solar energy industry. Compared with the European countries, Malaysia is definitely falling behind as the European governments have better incentives and schemes to promote the solar industry and increase the technology's generation capacity. Furthermore, Malaysia is only just beginning to promote solar energy. According to the MBIPV national project team leader and chief technical adviser, Ahmad Hadris Haris, it could therefore be challenging for Malaysia to continue attracting foreign investments in this area in the future, which would mean developing the local solar energy industry without the support of established players [26].

Table 1
Estimated percentage (%) contributions of energy sources in Malaysia in 2005 [11].

Source	Percentage, %
Gas	72.5
Coal	16.4
Hydropower	6.2
Diesel	3.2
Oil	0.8
Biomass	0.5
Others	0.3

Besides solar energy, the other renewable energies are solid waste, mini hydro, biogas and biomass. The growth of different types of renewable energy resources from 2011 to 2030 is shown in Fig. 2. From the figure, we can see that besides solar energy, the growth of biomass also increases every year. Malaysia has a significant amount of agriculture activities; thus, biomass can be a very promising alternative source of renewable energy. In fact, the fifth fuel policy of the Malaysian government stipulates that "to supplement the conventional energy supply, new sources, such as renewable energy, will be encouraged, and biomass, such as oil palm, wood waste products, and rice husks, will be used on a wider basis". Nevertheless, it is surprising that, even though biomass can be easily obtained in Malaysia, the use of biomass as a renewable energy source is still low. For instance, in 2005, biomass only contributed around 0.5% of total energy sources in Malaysia, as shown in Table 1 [11]. This observation shows that Malaysia is still reliant on fossil fuels for her main energy supply. Although Malaysia is blessed with numerous renewable resources such as solar, industrial and agricultural wastes, wind and others, they have low viability because of the high cost of harnessing energy from them [23]. Studies have shown that Malaysia would soon suffer from lack of energy security as Malaysia fossil fuel reserves are predicted to last only for another 30–40 years. After that, Malaysia will become a net importer of fossil fuels (mainly oil and gas). To address this drastic situation, the Malaysian government has been seeking reliable renewable energy sources that can replace fossil fuels, especially petroleum. With the increasing price of crude oil, the Malaysian government has spent a lot on subsidies to keep the cost

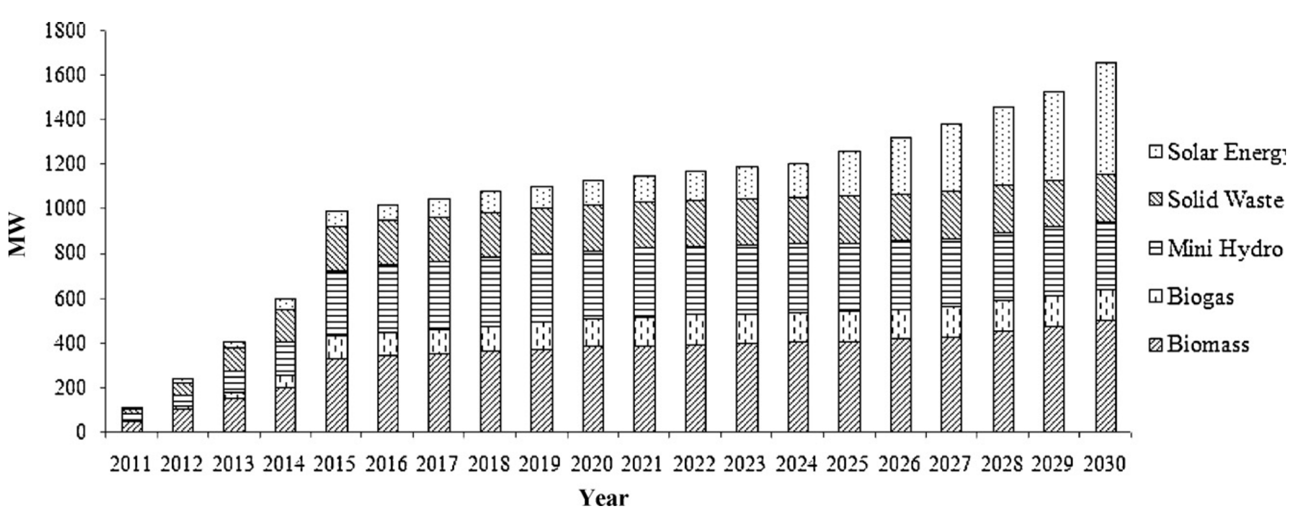


Fig. 2. The growth of different type renewable energy resources from 2011 to 2030 [27].

of energy, especially transportation fuel, low. In 2007, Malaysia's fuel subsidies cost the country about RM40 billion [11].

According to the 2011 Budget, the introduction of the Renewable Energy Act and the feed-in tariff mechanism, which are goals of the Renewable Energy Policy, are meant to promote the greater use of renewable energy to supplement the nation's depleting oil and gas reserves. Given that the country now relies heavily on fossil fuels, it is time to start promoting renewable energy aggressively. In the first 9 months of this year (2010), 54.3% of electricity generated in Peninsular Malaysia was sourced from gas, 39.8% from coal, 5.5% from hydroelectric and the balance from oil, diesel and biomass [28].

Because Malaysia is the world's second largest producer and exporter of palm oil (according to data from 2006), the oil palm biomass is used for the generation of heat in several applications. For example, the use of oil palm biomass in cogeneration, charcoal production, timber drying and electricity generation is well establish in Malaysia. In 2003, a total of biomass energy equivalent of 2500 ktoe (kilo tons) was utilized [23]. However, currently, the main use of biomass is to be converted into biofuels (mainly bioethanol), which can be used as a gasoline substitute for transportation fuel. This alternative fuel is crucial to reducing greenhouse gas emissions and transportation fuel prices. Biofuel using palm oil as a renewable source of energy is part of an initiative to make Malaysia a world leader for palm oil production and utilization. RE reduces the nation's oil dependence, improves the economy and helps to conserve the environment [12].

4. Biomass resources and its potential as bioethanol in Malaysia

Biomass is organic material that stores sunlight in the form of chemical energy. It is commonly recognized as a RE. During the growth of plants and trees, solar energy is stored as chemical energy via photosynthesis, which can be released through direct or indirect combustion [29]. In Malaysia, the National Energy Policy has established the importance of RE and highlighted the focus on renewable sources and environmental conservation. Biomass has been used as a substitute for fossil fuels in recent years. The energy in biomass is known as biomass energy or bio-energy. The growing interest in bio-energy will contribute to the reduction of poverty in developing countries, increase the sustainable energy supply and reduce the emission of CO_2. As a result, biomass is the most important bio-energy option at the present and is expected to maintain that position for the first half of this century. Biomass energy resources come from wood and wood waste, agricultural crops and their waste, municipal waste (MSW), animal waste and food waste. Presently, available biomass resources can provide around $6–10 \times 10^{15}$ Btu of feedstock energy. However, the main use of this bio-energy in developing countries, including Malaysia, is as firewood for cooking and heating [5]. In terms of the traditional uses of biomass, in 2005, 2.5 billion people used firewood, charcoal, agricultural waste and animal dung to meet most of their daily energy needs for cooking and heating. By 2015, the number of people using biomass for essential domestic purposes is expected to rise to 2.6 billion. This number is expected to further increase to 2.7 billion by 2030 as population numbers increase. This increase means that one-third of the world's population will still be relying on biomass fuels. However, the modern use of biomass is as a stand-alone fuel or a component in fuel blends, such as co-firing wood with coal, or mixing ethanol or biodiesel with conventional petroleum based fuels [24].

Malaysia is a tropical country located in South East Asia. It has an equatorial climate with fairly uniform temperatures throughout the year. In the lowlands, the temperature ranges from 32 °C during the day to 22 °C at night, whereas in the highlands, the temperature can drop to 15 °C. Rainfall is common throughout the year, averaging 200–250 cm a year [30]. The excellent weather and sufficient water supply for crops in Malaysia ensure good growing conditions and efficient photosynthesis. Therefore, high biomass yield can be achieved from the most photosynthetically efficient C-4 plants. Hence, biomass is an easily obtained energy source for countries such as Malaysia, which have large forests and agriculture-based economics and which have limited sources of energy [29].

The energy potential of biomass in Malaysia is estimated to be about 440 PJ/year in 1996. The total contribution of biomass to the primary energy supply of Malaysia has been estimated to be at least 90 PJ. At present, the main contribution to biomass is from palm-oil waste, which is about 80% of the total utilized biomass. Nevertheless, the total technical potential of biomass in Malaysia is around 130 PJ, which is about 5% of the national energy requirement [31]. For instance, Malaysian industries, such as sugar, palm oil, rice and wood, have been utilizing their biomass as fuel to cover some or all of their energy requirements [32]. In Malaysia, it is estimated that potentially 1340 MW of energy can generated from biomass by 2030. Currently, there is 39 MW installed capacity under construction as of July 2009 under the Biogen Project. The biomass involved is palm oil waste (EFB) and agricultural waste (wood chips, rice husk, etc.) [27]. Biomass is considered to be one of the main renewable energy resources of the future due to its large potential for economic viability and various social and environmental benefits. It is also estimated that, by 2050, biomass could provide nearly 38% of the world's direct fuel. Converting biomass into liquid fuels, such as ethanol, can supply much of our transportation fuel needs for cars, trucks, buses, airplanes and trains. This supply is very important, because nearly one-third of our nation's energy is now used for transportation [29].

Many different types of biomass can be grown for the express purpose of energy production. Two main factors determine whether a crop is suitable for energy use. Good energy crops have very high yields of dry material per unit of land (dry tons/hectare). A high yield will reduce land requirements and lower the cost of producing energy from biomass [5]. From Table 2, we can see that huge quantities of biomass are generated from oil palm crops; it will be a waste if this biomass is not properly utilized. Although oil palm biomass can be converted to various value-added products, its potential as a source of renewable energy seems to be more promising, considering the current state of the energy crisis with the price of crude oil petroleum increasing almost every day [11].

The following section shows the primary agricultural wastes or potential feedstock in Malaysia that can be converted into value-added products, such as second-generation bioethanol (SGB), to increase eco-efficiency and reduce waste generation.

4.1. Oil palm biomass

As the oil palm is a tropical palm tree, it can be cultivated easily in Malaysia. The oil palm tree in Malaysia originates from West Africa, where it grows wild. It was later developed into an agricultural crop. Because oil palm is a high yielding crop, it can produce, on average, about 4–5 ton of oil/ha/year. It has been forecasted that, in years to come, the demand will be higher with increasing world demand in oils and fats. It is already very profitable to invest in the oil palm industry in Malaysia, even using existing technology [32].

Malaysia has become the top palm oil exporter country. In 2008, Malaysia generated foreign exchange of US$ 20,000 million from exports of palm oil and palm oil-based products, such as vegetables oil and fats [12]. In the 1980s, Malaysia promoted a palm diesel program. The Malaysians Palm Oil Board (MPOB), in cooperation with PETRONAS, developed a special biodiesel production technology based on palm oil. However, the main purpose was the

Table 2
Biomass resources potential and their estimated energy potential in Malaysia.

Type of industry	Production (Mton)	Type of biomass	Residue generated (Mton)	Calorific value of biomass (kJ/kg)	Potential energy generated* (Mton)	References
Oil palm	59.80 c	Empty fruit bunches	12.30 c	18,838 a,b	5.53	a. [11]
		Fronds and trunk	21.10 a	–	–	b. [33]
		Fiber	8.75 c	19,068 a,b	3.99	c. [24]
		Shell	3.94 c	20,108 a,b	1.89	d. [34] (density of wood: 0.57 ton/m^3)
		Palm kernel	2.11 a	18,900 a,b	0.95	e. [35]
Paddy	2.14 c	Rice husk	0.47 c	15,324 e	0.17	f. [36]
		Rice straw	0.86 c	13,620 f	0.28	g. [37]
Sugar	1.11 c	Bagasse	0.36 c	8021 g	0.069	h. [38]
Wood	1.67 d	Sawdust	0.96 d	19,008–19,188 h	0.44	i. [39]
	0.30 d	Plywood residue	0.069 d	10,000–19,000 i	0.024	j. [40]
Municipal solid waste	11,940 ton per day	Municipal solid waste	–	9500 j	–	

* Potential energy generated (ton) = residue generated (ton) × 1000 kg × calorific value (kJ/kg)/41,868,000 kJ.

production of vitamin Q, carotene, lipids and other substances, and biodiesel was produced as a by-product [41]. Currently, Malaysia has mainly produced biodiesel, because it can be used as a substitute for fossil diesel in diesel engines. In Malaysia, the raw material for biodiesel production is crude palm oil (CPO). In 2005, the production of CPO was nearly 15 million tons, and it is forecasted to rise to nearly 18 million tons in 2020. In general, biodiesel production is already well-proven, off-the-shelf technology that can be purchased as turnkey plants with performance guarantees from many suppliers all around the world [42].

With the growth of palm oil production in Malaysia, the amount of residue generated also shows a corresponding increase. One hectare of oil palm can produce about 50–70 ton of biomass residues. Currently, Malaysia has huge resources of biomass from the palm oil industries, which contribute 85.5% of the more than 70 million tons of biomass [11]. Due to the huge amount of biomass generated yearly, Malaysia has the potential to utilize the biomass efficiently and effectively to make other value-added products, such as paper sheet, fiberboard, and paperboard. Nowadays, in addition to biodiesel, there are advanced technologies that can convert the oil palm biomass into useful renewable energy sources, such as bioethanol, which is an alternative fuel. Although bioethanol is still a relatively new idea in Malaysia, some countries, such as Brazil, Germany and France, have already been using this fuel for some time. Because bioethanol can be substituted for gasoline and used in the majority of vehicles in Malaysia, it is suitable for investment in Malaysia and potentially can help alleviate the oil crisis.

According to Fig. 3, there is an increasing trend of oil palm plantation expansion in Malaysia from 1975 to 2007. This expansion shows that the utilization of oil palm as a source of energy is certainly increasing [32]. The oil palm plantations will generate huge amount of waste, such as chopped trunks, dead fronds, empty fruit palm bunches (EFPB), shells and fibers. These wastes consist of biomass in the form of cellulose and lignocelluloses, and they are suitable for the production of second-generation bioethanol (SGB) [12,32].

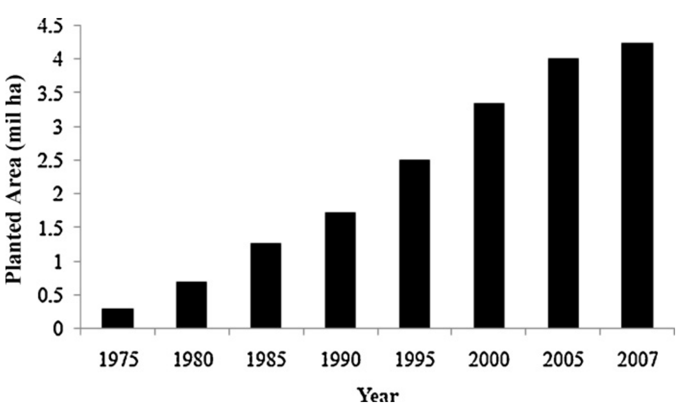


Fig. 3. Planted area of oil palm in Malaysia from 1975 to 2007 [43].

There was about 4.08 million ha of oil palm plantations in Malaysia in 2009. When the fresh fruit bunches are harvested from the trees, the oil inside the fruit bunches will be extracted, leaving behind a huge waste of empty fruit bunches (EFB). In 2009, it is estimated that around 747.20 million tons of EFB, MF and shells are collected during the pressing of sterilized fruits, as shown in Table 3. At the same time, the oil palms fronds are pruned when fresh fruit bunches are harvested to allow the cutting of ripe fruit bunches. Kelly-Yong et al. (2007) [75] reported that each hectare of oil palm plantation produces 10.88 ton of oil palm fronds on average. Furthermore, oil palm trunks are obtained during the re-plantation of oil palm trees. When the trees are chopped every 25 years, there are 2.515 ton of trunks generated from each hectare. The abundant availability of oil palm wastes, especially EFB and oil palm trunks, has great potential to be converted into second-generation bioethanol. EFB are rich in sugar. Recent research has shown that EFB can be used to produce glucose and xylose successfully. Thus, EFB can be used as a feedstock to produce second-generation bioethanol through hydrolysis and fermentation [11,32].

In addition, recent studies have shown that, compared to the rainforest, oil palm plantations are more effective "carbon sinks", i.e., areas of dry mass that can absorb harmful greenhouse gases. Thus, large oil palm plantations act as sequesters of carbon dioxide (CO_2) [11,32]. According to Kyoto Protocol, the carbon sink of oil palm can be converted to carbon credit, which can potentially be traded. In addition, the oil palm forest also assimilates 44 ton of dry matter/ha/year compared to 25.7 ton by a rainforest. Dry-matter production remains high throughout the 25-year economic lifecycle of the oil palm forest. Studies have shown that oil palm will absorb CO_2 and return oxygen (O_2) to the atmosphere more than others plant [32]. Therefore, the conversion of oil palm biomass into second-generation bioethanol to be used as transport fuel can further reduce the emission of CO_2 and conservation of environment can be achieved.

4.2. Wood waste

Another potential source for SGB is wood waste. Wood waste is mostly found in logging activities. The total land area in Malaysia is 32.98 million ha. In 2009, the total production of logs based on the total land area is 18.27 million cm^3, as shown in Table 4 [45]. According to the Malaysia Timber Council, Malaysia has generated a Free On Board (FOB) value of more than RM202 million from January to February 2009 through logging activities. Malaysia

Table 3
Bioethanol potential of oil palm biomass in Malaysia in 2009 [44].

State	Total area of oil palm plantations (ha)	Area harvested (ha)	Fresh fruit bunches production (ton/ha)	Oil yield (ton/ha)	Bioethanol potential/residue production (ton/ha)	Total residue (Mton)
Johor	712,448	632,510	18.88	3.74	15.14	9.58
Kedah	78,384	74,702	22.50	4.44	18.06	1.35
Kelantan	113,185	84,851	12.62	2.58	10.04	0.85
Melaka	51,193	48,451	23.88	4.87	19.01	0.92
N. Sembilan	166,501	150,969	19.74	3.97	15.77	2.38
Pahang	675,667	587,698	19.36	3.91	15.45	9.08
P. Pinang	13,588	13,319	17.90	3.48	14.42	0.19
Perak	373,854	338,737	23.22	4.58	18.64	6.31
Perlis	234	234	–	–	–	–
Selangor	139,544	128,312	21.12	4.17	16.95	2.17
Terengganu	165,216	136,861	13.93	2.76	11.17	1.53
Sabah	1,361,598	1,233,056	21.15	4.52	16.63	20.51
Sarawak	839,748	646,002	15.29	3.24	12.05	7.78
Total	4,691,160	4,075,702	229.59	46.26	183.33	747.20

Table 4
Log production in Malaysia in 2009 [45].

Region	Land area (millionha)	Permanent reserved forest production (million cm^3)	Stateland production (million cm^3)	Others production (million cm^3)
Peninsular Malaysia	13.18	2.40	1.05	0.24
Sabah	7.48	3.98	0.02	0.26
Sarawak	12.32	7.90	2.40	–
Total	32.98	18.27		

has produced 438,340 m^3 of logs, 270,891 m^3 of sawn timber and 683,498,732 m^3 of plywood in 2009 [46]. In addition to profits, these industries generate a huge amount of wood waste, which can potentially give rise to environmentally sensitive disposal issues. This concern is particularly true in sawmills. To fully utilize the waste, it can be used as a feedstock for the production of SGB. According to Hoi [47], the production of timber product will generate an enormous amount of wood waste, such as logging residue, primary manufacturing residue, plywood residue and secondary residue, which is shown in Table 5.

Malaysia is an important timber producer, along with other countries such as Brazil, Indonesia, Thailand and the Philippines [48]. According to Table 6 [49], the Malaysia timber industry is immature compared to the wood industry in the rest of the world. It produces around 1–1.5% of the total world production in 2000, 2006 and 2008. To reduce pressure on native forest as a source for raw materials and to ensure its continuous availability for the domestic timber industry, the Malaysian government is encouraging the development of large-scale commercial forest plantations. In line with this policy, in March 2005, the Cabinet tasked the Ministry of Plantation Industries and Commodities (KPPK) to pursue an aggressive program for the development of forest plantations in Malaysia. Under this program, the Ministry has planned to develop 375,000 ha of forest plantation at an annual planting rate of 25,000 ha per year for the next 15 years. Once successfully implemented, every 25,000 ha of land planted is expected to produce 5 million cubic meters of timber [50]. Therefore, this program will increase the quantity of wood residue every year, which can be potential feedstock for the production of SGB.

Table 5
Quantity of wood residue generated in Malaysia [47].

Type of wood residue	Waste volume (million cm^3)
Logging residue	5.10
Primary manufacturing residue	2.20
Plywood residue	0.91
Secondary residue	0.90
Total residue	9.83

4.3. Rice/paddy biomass

Rice is a staple crop in many countries and is abundantly produced in many parts of the world. In Malaysia, rice is the main food crop and is grown on small farms. Despite the widespread advances brought about by the introduction of improved plant varieties and chemical fertilizers and pesticides, rice production declined steadily during the second half of the 20th century. The main causes of this decline were unfavorable weather conditions and the loss of farm labor to urban manufacturing jobs. Increasingly deficient in rice production, the country has been forced to make up the shortfall with imports, chiefly from Thailand. Consequently, the government has taken measures to raise its self-sufficiency in rice, largely by implementing programs to consolidate smallholdings and increase labor productivity through group farming schemes. By 2000, Malaysia's rice production had begun to rise, despite the continued labor shortage [51].

According to Table 7 [52], there is an increase in rice production from 2004 to 2009 of about 7.88%. Due to the demand for rice, the paddy plantation area and yield of paddy per ha has also increased consistently every year. Meanwhile, rice production generates a huge amount of paddy and rice residue. Hence, rice crops also have significant bioethanol production potential given the increasing production year by year. However, the production of bioethanol from food crops such as rice grain (first generation biofuels) has resulted in an undesirable direct competition with the food supply because most rice is used for human consumption [53]. Recent studies have shown that about 4.8% of the world's rice production is lost as waste. In Asia, about 22 million tons of dry rice is wasted, larger than the rice production of any other region [54]. Therefore, using an abundant inedible plant material, such as rice husk and rice straw, as feedstock should help to reduce pressure on food crops.

Rice biomass, such as rice husk and rice straw, can be used for producing bioethanol because it contains a significant amount of sugars, such as holocellulose. The composition of rice crops and its residue can be seen in Table 8 [53,55]. Rice husk is traditionally used as domestic and industrial fuel in developing countries like India. The high ash content of rice husk limits the carbon conversion efficiency of the pyrolysis of rice husk. Rice husk is a potential

Table 6
World production of industrial roundwood [49].

Country	2000		2006		2008	
	'000 m^3	%	'000 m^3	%	'000 m^3	%
Malaysia	24,380	1.52	22,506	1.35	22,190	1.43
Asia	230,837	14.35	230,999	13.88	243,364	15.63
World	1,608,158	100	1,663,995	100	1,556,687	100

Table 7
Paddy plantation area and production in Malaysia from 2004 to 2009 [52].

Item	2004	2005	2006	2007	2008	2009
Planted paddy area (Ha)	667,310	666,781	676,074	676,111	656,602	672,304
Average yield of paddy (kg/ha)	3434	3471	3236	3514	3584	3660
Paddy production ('000 ton)	2291	2314	2187	2375	2353	2460
Rice production ('000 ton)	1461	1490	1407	1531	1516	1586

Table 8
Composition of rice crops and their residue [53,55].

	Starch (wt%)	Cellulose (wt%)	Hemicelluloses (wt%)	Lignin (wt%)	Ash (wt%)	Ethanol yield (L/dry-t)	Gasoline equivalent (L)
Rice	87	–	–	–	–	511	369.75
Rice straw	–	43	25	12	20	373	269.89
Rice husk	–	35	25	20	20	328	237.33

alternative substrate for bioethanol production because it can generate additional revenues from the high calorific value lignin obtained after bioethanol production. Therefore, lower cost, abundance and potentially high-yield ethanol make rice husk an excellent prospective source of raw material for ethanol production [56]. Banerjee et al. have reported that the pre-treatment of rice husk using the wet air oxidation (WAO) method produces a high yield of cellulose content that can support the subsequent enzymatic hydrolysis and fermentation steps of ethanol production.

Rice straw is another type of rice biomass obtained in the rice mills. Rice straw consists of several characteristics that make it a potential feedstock for ethanol production. It has high cellulose and hemicellulose content that can be readily hydrolyzed into fermentable sugars [53]. The high ethanol yields from rice straw and rice husk exceed the yield from rice grain, which are about 190 L (liter) of ethanol per ton of rice straw and rice husk. The use of rice straw also avoids the use of a food grain to produce energy sources like ethanol to replace gasoline.

The generation of rice husk and straw at the rice mill creates the problem of disposal. Conventionally, rice husk and straw are dumped in landfills. This dumping creates an environmental hazard when the husk begins to biodegrade, producing methane gas that escapes into the atmosphere [31]. For rice straw, its limitations, such as low bulk density, slow degradation in the soil, harboring of rice stem disease and high mineral content, also contribute to the waste disposal problem [53]. Sometimes, millers even resort to burning rice husk and rice straw in the open. Because rice husk does not burn easily, it tends to smolder and produce smoke, which contributes to air pollution and consequently affects public health [31,53]. To reduce land filling and field burning, this waste can be converted into useful fuels, such as SGB, for the generation of electricity and for use as transport fuel.

5. Second-generation bioethanol

Malaysia is the world's second largest producer as well as the world's largest exporter of palm oil. In Malaysia, biofuel development has been focused on the production of palm oil-based biodiesel, while ethanol production is negligible. Nevertheless, between 2001 and 2006 alone, the global annual production of bioethanol grew by 23%. Compared to 2007, global fuel ethanol production grew 31% to 35 million tons of ethanol (toe) (1.2 million barrels daily) in 2008, with the following distribution: North America (52.5%), South America (39.4%), Europe (3.8%) and Asia Pacific (4.6%). This trend indicates that the global bioethanol industry will continue its rapid growth in succeeding years [4].

Ethanol (ethyl alcohol or EtOH) is an attractive alternative fuel because it is a renewable bio-based resource. Because it is an oxygenated fuel, ethanol can reduce particulate emissions in compression-ignition engines. Ethanol can be produced from different kinds of raw materials. The raw material can be classified into three categories: sugar, starch and lignocellulose-based material [5]. The use of lignocellulosic biomass from agricultural residues, wood, fast-growing trees, perennial grasses, macro-algae and municipal waste is the future technology of ethanol conversion. Lignocelluloses need to be broken down by a combination of physical, chemical or enzymic steps into sugars, which may subsequently be fermented to produce biofuel or converted into synthetic biofuels by thermochemical routes, such as gasification and pyrolysis [4].

Because biomass is the most attractive option for Malaysia due to the huge amount of agriculture waste produced every year, the Biomass Power Generation & Cogeneration Project (BioGen), which was jointly funded by the United Nations Development Program (UNDP), Global Environment Facility, Government of Malaysia and the Malaysians private sectors, was commissioned. The mission of this project was to reduce the growth rate of GHG emission from fossil fuel combustion processes, while simultaneously reducing the unused waste residue from palm oil and catalyzing the wider adoption of grid-connected biomass-based power generation and cogeneration. The production of bioethanol from lignocellulosic agriculture waste provides another alternative option to convert these wastes into valuable products [12]. The use of "second-generation" cellulosic biomass ethanol has significant advantages over the use of first generation bioethanol based on food crops, as cellulosic biomass is more abundant than edible plants. Utilizing cellulosic biomass would thus help to reduce competition with food production for land, water and other resources. It is therefore necessary to devote greater efforts to develop and deploy second-generation bioethanol technologies, because it is substantially more beneficial [4,57]. The main purpose of derived bioethanol is as a fuel additive to cut down a vehicle's carbon monoxide and other

smog-causing emissions. For instance, flexible-fuel vehicles, which run on mixtures of gasoline and up to 85% of ethanol made from biomass, are now available in Brazil, the US and Europe [11].

6. The key drivers for the development of second-generation bioethanol in Malaysia

6.1. Security of energy supply

The domestic energy landscape has changed considerably over the years. Although it was an energy-rich country a decade ago, Malaysia will soon be joining other countries that have to rely on imports to meet domestic demand. Hence, energy security is a crucial issue that needs to be addressed to support the economy's trajectory towards higher growth [58]. Malaysia is a developing country that is well endowed with natural resources that provide the raw materials for wealth-creating economic activity, such as rubber, palm oil, tin, petroleum and natural gas. This natural wealth has provided the basis for transforming Malaysia from a country reliant on primary production into an industrialized society over the last few decades. As trade with the world, especially exports, had continued to expand, Malaysia has built numerous manufacturing industries. With improvements in the quality life of the Malaysian population, there will be an increase in energy consumption [25].

Over the outlook period, final energy demand is projected to grow at 3.9% per year, reaching 98.7 Mtoe in 2030, nearly three times the 2002 level. The industry sector will have the highest growth rate of 4.3%, followed by transport at 3.9%, residential at 3.1% and commercial at 2.7%, as shown in Fig. 4. Given this outlook, the Malaysian government introduced the ninth 5-year plan (2006–2010), which emphasized the security, reliability and cost-effectiveness of energy supply by focusing on the sustainable development of the energy sector. This plan has introduced renewable energy sources as the economy's fifth fuel after oil, coal, natural gas and hydro to sustain future energy demand [59]. Nevertheless, the transport sector has become the largest consumer of energy in Malaysia, accounting for 40.6%, 40.5% and 41.1% of the total energy demand in 2000, 2005 and 2010, respectively, as shown in Table 9 [25].

The transportation sector has therefore become the main driver of increasing liquid fuel demand. Although Malaysia has its own oil fields, it is still heavily dependent on imported oil to satisfy the demands of its transportation sector. Therefore, Malaysia energy security can be considered to be in a fragile condition. Recently, the development of renewable energy technologies and policies, particularly those that promote the expansion of biofuel production, is believed to be one path to achieving energy security [4]. Because the main energy demand in Malaysia is contributed by the transportation sector, the development and utilization of biofuel as a substitute for fossil fuel has become vital. In 2005, the introduction of biodiesel for the transportation sector is one of the positive steps that the government has undertaken to achieve sustainable energy development through the diversification of fuel sources. The transportation sector of Malaysia is heavily reliant on the road transport sub-sector. In 2002, for example, energy demand for road transport represented 86% of the total transport energy demand. Urban transport, such as in Kuala Lumpur, is heavily dependent on passenger vehicles because rail infrastructure has not yet been sufficiently well developed to connect the city center with the residential suburbs. Inter-city passenger and freight movement depends on road transport because of the limited availability of rail transport. The Malaysian government has promoted passenger vehicle ownership as it considers the auto manufacturing industry as an important driver for economic development. As a result, Malaysia has a relatively high level of passenger vehicle ownership of about 180 vehicles per 1000 populations in 2002 [59].

The Malaysian vehicle fleet can be divided into passenger cars, motorcycles, good vehicles and buses. In 2003, gasoline and diesel consumption accounted for nearly 87% of the total energy consumption in the transportation sector. A total of 7734 ktoe of gasoline and 4970 ktoe of diesel were consumed. It is expected that these figures will double by 2020. Studies have shown that the predicted consumption of gasoline in Malaysia is more than that of diesel oil from 2005 to 2020, as shown in Fig. 5 and Table 10. According to Table 10, almost 100% of the passenger cars in Malaysia

Table 9
Energy demand by sector in Malaysia, 2000–2010 [25].

Source	Petajoules (PJ)			Percent of total (%)		
	2000	2005	2010	2000	2005	2010
Industrial	477.6	630.7	859.9	38.4	38.6	38.8
Transport	505.5	661.3	911.7	40.6	40.5	41.1
Residential and commercial	162.0	213.0	284.9	13.0	13.1	12.8
Non-energy	94.2	118.7	144.7	7.6	7.3	6.5
Agriculture and forestry	4.4	8.0	16.7	0.4	0.5	0.8
Total	1243.7	1631.7	2217.9	100.0	100.0	100.0

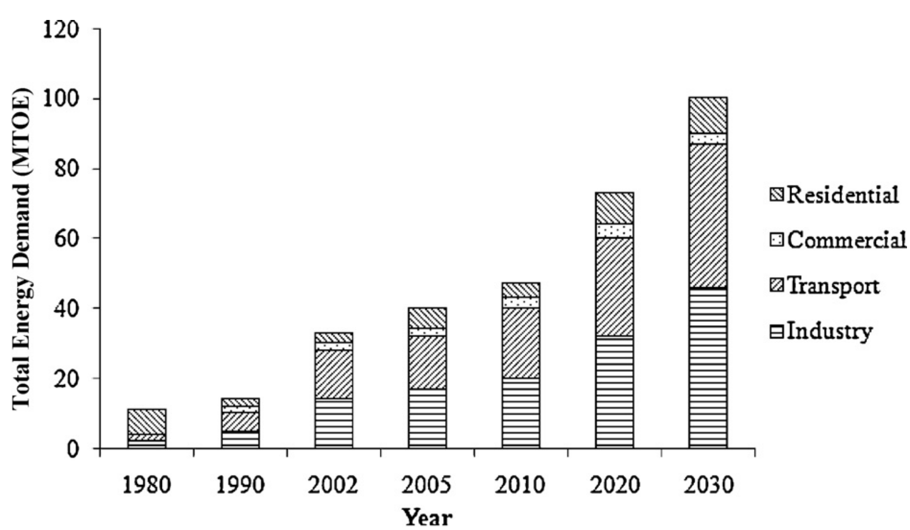


Fig. 4. Estimated total energy demand by sector in Malaysia over the outlook period [59].

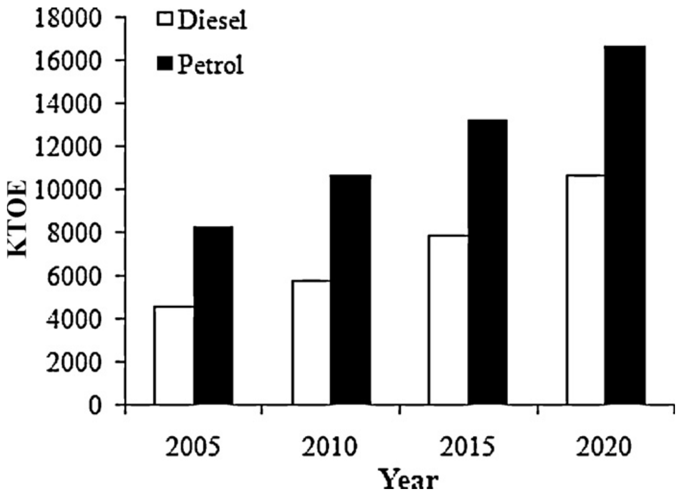


Fig. 5. Predicted gasoline and petrol consumption in the Malaysian transportation sector [42].

are powered by gasoline, while about 74% of buses and trucks are fuelled by diesel [42].

In 2004, for instance, gasoline-powered cars make up the greatest percentage of passenger cars at 83%, while diesel-powered cars make up only 3%, as shown in Table 11. The total number of vehicles in use in Malaysia was 5,393,035 [8]. Although the Malaysian government is promoting biodiesel as a new energy fuel in Malaysia, gasoline, rather than diesel fuel, is the more commonly used liquid fuel in Malaysia. Therefore, the development of bioethanol is more important than the development of diesel fuel as it can replace gasoline in vehicles. According to the Tenth Malaysian Plan, blending of biofuel in the transport sector will be made mandatory from 2011, further enhancing fuel security.

6.2. Economic feasibility of biomass conversion ethanol

Malaysia is a country blessed with petroleum resources. However, it is relatively a small producer in the international arena. Malaysia's oil reserves of about 5.5 billion barrels are relatively small compared to those in Saudi Arabia (260 billion barrels), Iran (138 billion barrels) and Iraq (115 billion barrels). For the longer term, efforts to maintain the present level of oil production of about 660,000 barrels per day could be challenging. Over the years, our geological structure has matured. All major discoveries have already been developed and in production for more than 30 years. In fact, our oil and gas reserves are now depleting. In addition, the remaining oil and gas fields are of lower quality due to high carbon dioxide content. The development of these fields will be more challenging due to the physical nature of the fields, which are relatively small, scattered and faraway from the existing production facilities. Therefore, the cost of developing future resources will be much higher and, hence, may not be economically feasible [58]. The rationale for the introduction of biofuels for the Malaysian transportation sector is that the sector currently consumes above 40% of the total energy consumption according to Table 9 and is today 100% dependent on fossil fuels. The energy forecasted shows that there will be a doubling of the fuel consumption for road transport from 2004 to 2020. Without a change of energy strategy, Malaysia will switch from its present status as oil supplier to a future (2014) importer of oil [42]. This switch will cause an economic downturn and decrease Malaysia's Gross Domestic Product (GDP).

Malaysia's economy is expected to grow strongly over the outlook period with an annual average growth rate projected at 4.8%. UN Habitat projections show that the share of Malaysia's urban population will reach 78% in 2030 from 63% 2002. This factor, combined with high per capita GDP growth of 3.4% per annum over the outlook period, will lead to a change in lifestyle and cause a substantial growth in the energy demand for the transport, commercial and residential sectors. Fig. 6 shows Malaysia's GDP and urban population over the outlook period [59].

To increase Malaysia's GDP, it is necessary to discover a new energy fuel substitute for fossil fuels, which the transportation sector is highly dependent on. In Malaysia, gasoline is the main energy fuel use in vehicles, as shown in Table 11 [8]. Therefore, the development of bioethanol as the main energy fuel in Malaysia is highly recommended. Renewable energy sources are abundant in Malaysia, especially biomass. Therefore, developing cellulosic ethanol (SGB) is more important than developing sugar-based crop ethanol, because the former will not compete with the food supply. At the same time, it can act as a new product to drive the Malaysian economy and increase the GDP.

Although the energy intensity with respect to Malaysia's GDP has shown an increasing trend over the years, the energy market in Malaysia is highly distorted. Although petroleum products, such as petrol and diesel, are linked to market prices, gas prices and electricity tariffs are regulated by the Government. Energy prices have also been used as a means to extend assistance to selected groups as well as to attract foreign direct investments (FDI). This situation is untenable. Such practices have led to non-optimal allocation of resources and a host of other ill effects. Despite the fact that renewable sources, such as biomass, are not yet appropriate for widespread use, we have to bear in mind that our oil and gas resources are finite and non-replaceable. Therefore, developing a new renewable energy fuel is crucial to avert the situation where Malaysia becomes a net importer of energy in future [58].

From 2008, the Malaysian government has provided subsidies on petrol to decrease the burden on the people. The subsidized rates depend on the eligible vehicle categories. In June 2008, the Malaysian government cut the fuel subsidy because it could no longer afford the subsidy due to skyrocketing fuel prices. The fuel subsidies have cost the Malaysian government RM56 billion in this year, which is about half of the government's revenue. Petrol prices rose by 78 sen, which is a 41% jump from RM1.92 per liter to RM2.70 per liter. This increase means that those people who previously spent RM2000 per month to fill the tanks of their BMWs are now paying RM2820. Regardless of income levels, it is likely that most Malaysians will feel the pinch. Although the Malaysian government

Table 10
The predicted number of vehicles divided into fuel type [42].

Year	Type of fuel	Type of vehicle		
		Passengers cars	Buses	Lorries
2005	Petrol	5,837,738	5997	237,885
	Diesel	22,177	56,851	638,276
2010	Petrol	7,586,159	7810	336,023
	Diesel	28,819	74,044	901,593
2015	Petrol	9,447,802	10,039	467,064
	Diesel	35,891	95,177	1,253,192
2020	Petrol	11,396,563	12,797	642,038
	Diesel	43,294	121,327	1,722,671

Table 11
Vehicle types and fleet composition for each type vehicle type in Malaysia [8].

Vehicle type	Vehicle stock (%)	Average annual fuel consumption (L/vehicle)
Car (gasoline)	83.0	1500
Car (diesel)	2.6	1500
Bus	0.49	5000
Good vehicle	14.0	5700
Total	100.0	13,700

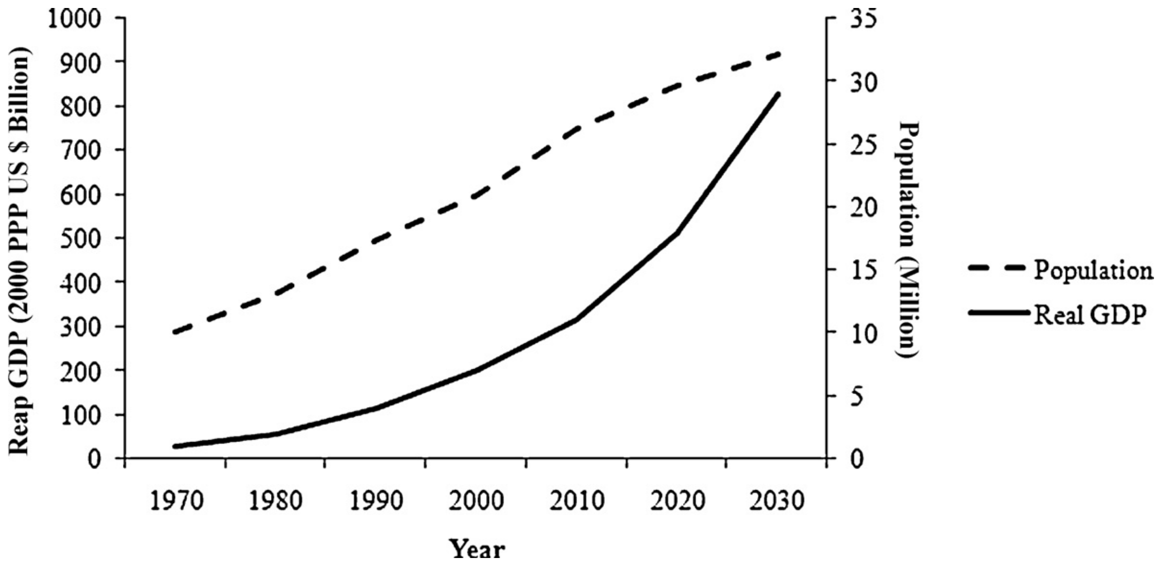


Fig. 6. Estimated GDP and urban population in Malaysia over the outlook period [59].

is ready to cut the fuel subsidy, it would replace the subsidy with cash for motorcycles and cars below a certain engine size, especially those made by local carmakers Proton and Perdua, which are the majority of vehicles in Malaysia. The fuel subsidy therefore still remains. Deputy Prime Minister Najib Razak (2008) has reported that the fuel subsidy is the biggest amount in the Ninth Malaysian Plan. The nation needs to wean itself from subsidies. When fossil fuels are gradually depleted, fuel prices will increase. The era of cheap oil and gas is over; thus, it is vital to use a promising renewable source such as biomass and convert it into ethanol to substitute for gasoline in Malaysia vehicles. The longer we delay to develop this new energy fuel, the more profound the impact on us at a later stage, especially for the future generation [60]. Taking all the components of bioethanol production into consideration, the cost price of bioethanol is estimated to be RM1.50/gasoline-equivalent liter. The price of gasoline is dependent on the world oil market price. The average crude oil is about 47 USD/bbl; thus, the production cost is calculated to be RM1.35/liter. By mixing bioethanol and gasoline in an E10 (10% ethanol blend in gasoline), the fuel price would be ($0.90 \times 1.35 + 0.10 \times 1.50$=) RM1.37/liter [41]. Therefore, a 10% ethanol blend in gasoline (E10) is economically feasible for the consumer.

Development of bioethanol is a new idea for the Malaysian fuel industry, and it does not have much experience in this field. To study the processing of bioethanol, Malaysia should therefore rely on the experience of foreign countries, especially the US, Canada and Brazil. In Malaysia, the huge availability of biomass makes production of cellulosic ethanol more advantageous than the production of sugar-based ethanol. Studies show that the production cost of ethanol from sugar beet is about 15–25€/GJ, whereas the production cost from cellulosic material is estimated at 5–15€/GJ. The lower production cost is even more pronounced for advanced technologies. Brazil is the world leader in the production of ethanol and the world's largest exporter of ethanol from sugarcane. Ethanol production from sugarcane is very economical in Brazil because the Brazilian government dropped sugar prices to support the ethanol industry. Brazil has devoted a land area to the cultivation of sugarcane for ethanol production, so that it is not in competition with land devoted for food production. As a result, the cost of production ethanol in Brazil is in the $0.68–$0.95 per gallon range [5,61]. This observation indicates that economic improvements through bioethanol development are likely to vary between countries due to the availability of different energy sources and government policy.

Bioethanol can substitute for fossil fuels in many applications, especially as an automotive fuel. For cellulosic ethanol production, the feedstock biomass is cheap and abundantly available throughout the year in Malaysia. However, ethanol conversion technologies from biomass requires much more processing than from sugars. Therefore, the production cost of cellulosic ethanol is an important factor in assessing the potential of bioethanol production in Malaysia. In comparison with the production cost of petrol fuel and cellulosic ethanol in Malaysia, petrol fuel and bioethanol from biomass prices are estimated to be RM21.7 GJ^{-1} and RM23.8 GJ^{-1}, respectively. Alhough the production cost of bioethanol from biomass is much higher than that of fossil fuel, it should be noted that the production cost depends heavily on the cost of feedstock. Almost 46% of the production cost is from the cost of feedstock. Therefore, utilizing a cheap and highly abundant raw material will further reduce the cost of bioethanol. This strategy may be the key to making the entire process economically feasible [11]. Agricultural crops in Malaysia, for instance, oil palm biomass, produced an average of 231.5 kg dry weight per year. These biomasses have high potential to be turned into bioethanol, especially empty fruit bunches (EFB), which is the highest contributor of oil palm biomass at about 15.8 Mton per year [32]. A test done at Denmark's Technical University (DTU), a Danish center for biofuels, in 2005 has shown that 1 ton of dry matter (DM) from EFB has the capacity to produce 388 l ethanol on basis of their Danish Bioethanol technology. Table 12 shows the potential of bioethanol production from EFB in Malaysia [41,42]. The forecasts estimate that 3% of the Malaysian EFB (230,000 ton dry EFB) may be used for bioethanol production in 2015, substituting about 2% (312 million liters) of the Malaysian petrol consumption. This result indicates that the conversion of ethanol from biomass is economically feasible.

6.3. Environmental impacts/climate change

As the country recognizes its rich natural heritage and abundant energy resources and their contribution to strong and continued development, there is also increasing awareness about the need to safeguard the environment, to harmonize development and environmental goals and to incorporate the framework of sustainable development into mainstream development planning. As the magnitude and array of environmental problems become more complex and urgent, there is a need to find approaches and methodologies

Table 12
Potential of bioethanol production from EFB in Malaysia [41,42].

Year	Projected EFB production (mio. t DM/year)	Potential bioethanol production (mio. l/year)	Energy content in ethanol (GJ/year)	Potential bioethanol (ktoe/year)
2005	6,140,000	2,382,000	54,793,360	1863
2006	7,590,000	2,945,000	67,733,160	2303
2025	7,660,000	2,972,000	68,357,840	2324

that can deal with these challenges effectively and efficiently. In Malaysia, environmental issues and natural resource management are coordinated through the Ministry of Natural Resources and Environment (NRE), the National Physical Plan (NPP) 2005–2010 and the National Biodiversity-Biotechnology Council (NBBC). Since the December 2004 Asian Tsunami, there has been increased focus on the conservation and rehabilitation of coastal natural resources, especially mangrove forests, and more attention is being put on linking land management and planning with climate change [62].

Furthermore, the need for fossil fuel for generating electricity and vehicle fuel has resulted in increasing oil extraction from the sea. Although technology has made oil extraction more efficient, the world is still using less productive methods, such as deep sea drilling, to extract the oil. However, this kind of extraction is not environmentally friendly, because it destroys the marine ecology. In addition, as the human population increases, the consumption of resources also increases. Therefore, the people from the developing countries, such as Malaysia, will adopt more energy-intensive lifestyles. According to Table 13, the population of Malaysia has reached 28.25 million in 2010 [63].

Besides the increase in energy consumption from population growth, increases in carbon emissions from power plants, industrial plants and the transportation sector are also one of the problems from population growth. Carbon emissions, including greenhouse gases such as carbon dioxide, have been increasing since the industrial revolution. For instance, the People's Republic of China (PRC) has become the world's largest emitter of carbon dioxide, while India had been forecasted to rank third by the end of 2008 [4]. Over the outlook period for Malaysia, CO_2 emissions from the energy sector are projected to grow at 4.2% per annum, reaching 414 million tons of CO_2 in 2030, a threefold increase over 2002. The electricity sector will be the biggest contributor to the incremental growth in CO_2 emissions at 49%, followed by the transportation sector at 28% and the industry sector at 20%, as shown in Fig. 7 [59].

According to Goldemberg 2008 [64], about half the world's oil production is consumed by road vehicles. Motor vehicles account for more than 70% of global CO emissions and 19% CO_2 emissions. About 8.8 kg of CO_2 is emitted from a gallon of gasoline [5]. According to the EIA, total CO_2 emissions in Malaysia from the consumption of fossil fuels increased tremendously from 1980 to 2008, as shown in Fig. 8 [65]. The increasing CO_2 emissions are due to increases in the total primary energy consumption in Malaysia. The total energy production from 2004 to 2008 was 18.267 quadrillion Btu, as shown in Table 14 [66]. It can be seen that when the petroleum consumption increased, the emission of CO_2 also increased. However, from 2006, oil production decreased as Malaysia began to produce biofuel to fulfill the energy usage in the country. In 2008, CO_2 emissions are 72.161 million metric tons, which is lower than the year before. Therefore, biofuel is one of the key options to mitigate GHG emissions and substitute for fossil fuels. Producing and using biofuels such as bioethanol for transportation offer alternatives to fossil fuels that can help provide solutions to many environmental problems.

Table 13
Population in Malaysia 2006–2010 [63].

	Year				
	2006	2007	2008	2009	2010
Total population (in million)	26.83	27.19	27.54	27.90	28.25

Biofuels are considered to be carbon neutral because all CO_2 emissions during biofuel combustion are offset by carbon fixation during plant growth. However, some GHGs may be released during biofuel production. Studies over the past 15 years have shown that the displacement of gasoline or diesel by biofuels can result in an average net reduction in GHGs emissions of 31% for bioethanol, 54% for biodiesel and 71% for cellulosic ethanol [67]. In all of these studies, the production of cellulosic ethanol was found to be significantly more beneficial than the production of sugar-based ethanol and biodiesel because of its zero net of CO_2 emission properties. Using ethanol-blended fuel for automobiles can significantly reduce petroleum use and exhaust greenhouse gases (GHG) emissions. In Malaysia, potential energy crops, such as oil palm biomass, are very attractive for produce biofuel production, especially bioethanol. Compared to the rainforest, oil palm plantations are more effective "carbon sinks". In addition, the combustion of oil palm biomass does not contribute to the net amount of carbon in the atmosphere as carbon is assimilated during plant growth [5].

7. Future SGB development perspectives

In Malaysia, the renewable energy (RE) sector still in its infancy. However, through the RE policies and projects that the government is now conducting, RE will be successful within the next few years. Through the development of biodiesel, Malaysia has become one of the major players in Asia's biodiesel market. This essay highlights the present and future needs in energy market for Malaysia. Today, Malaysia has become one of the largest producers of oil palm in the world and is expected to play a major role in the global biodiesel market. Although biodiesel can substitute for fossil fuels in vehicles, the types of oil crops are limited compared with agriculture waste. Furthermore, the fluctuation of palm oil price in the international market has resulted in an insecure raw material supply for the biodiesel industry. Therefore, the development of SGB is imperative because of its potential as a transport fuel substitute and its cheap feedstock crops that is abundant and available throughout the year.

Malaysia has started to produce bioethanol on a small scale in recent years. For instance, according to Bernama 2007 [68], a local company called Pioneer Bio Industries Corp Sdn Bhd is investing in a project to produce ethanol from Nipah palm trees. Nipah palm ethanol is normally produced by the fermentation of the sap from nipah palm trees. Chairman Md Badrul Shah Mohd Noor estimated that the company would be investing a total of RM43.2 billion over the next 3 years for the ethanol production project in Perak. This investment includes the building of nine refinery plants at areas where the company has been given the right to tap nipah sap. The company also claims that Nipah palm can produce 6.48 billion liters of ethanol yearly when its planned refineries begin operations in 2009. Other than this project, in 2009, Professor Kopli Bujang from the Faculty of Resource Science and Technology of Universiti Malaysia Sarawak (Unimas) has planned to produce bioethanol from sago palm. He had expected that the bioethanol plant in Unimas would begin operations in December 2009. Sago-based

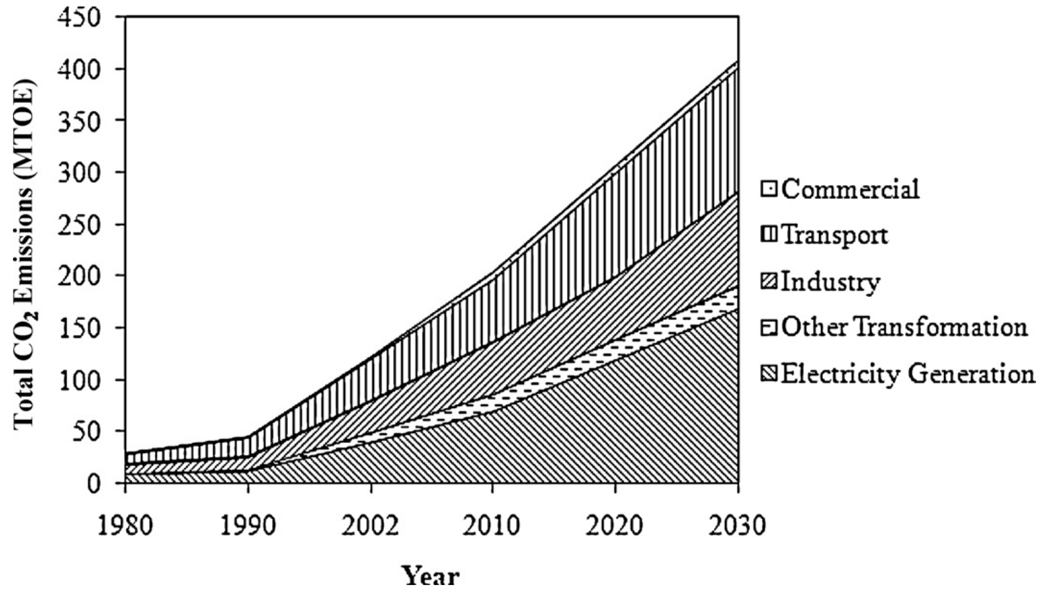


Fig. 7. Predicted CO_2 emission by sector in Malaysia [59].

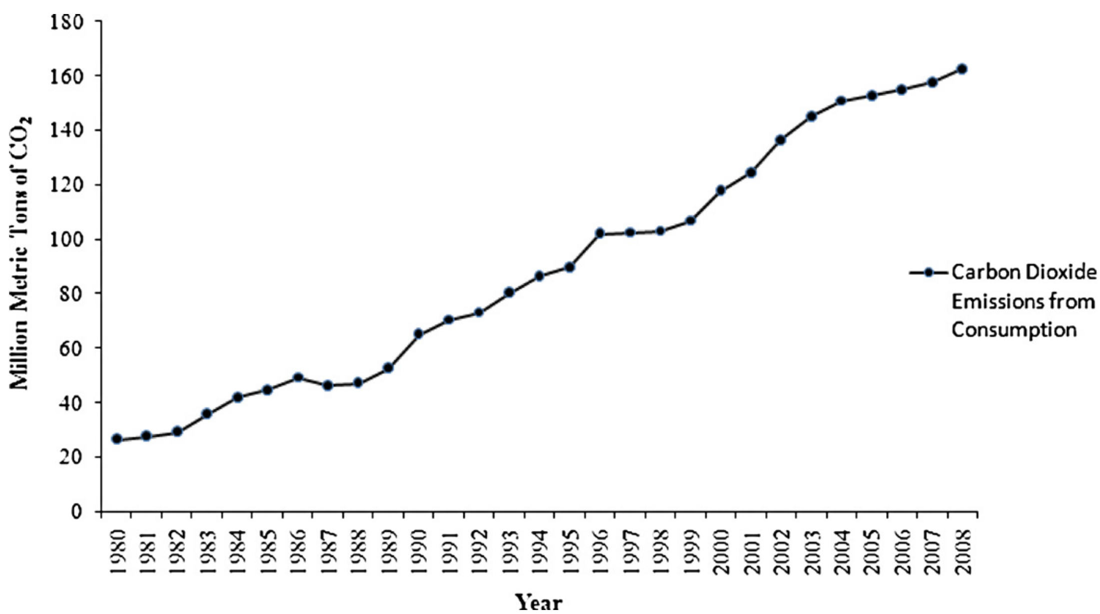


Fig. 8. Total CO_2 emission from the consumption of fossil fuels [65].

bioethanol will be named as E18 and can be used as an additive to petroleum with no modification of the car engine required. Meanwhile, sago-based bioethanol was expected to be in the market by February 2010. At the same time, the Science, Technology and Innovation Ministry agreed to issue a RM11.6 million funding from its Techno Fund to this plant [69].

Even though Malaysia initially invested in the development of first-generation bioethanol, second-generation bioethanol will continue to be vigorously pursued by Malaysia, as can be seen from the Asia-Oceania Convention on the Global Sustainable Bioenergy Project 2010. The speaker stressed the importance of using SGB as an advanced fuel for the Malaysian transportation sector because a

Table 14
Energy, oil and environment data in Malaysia 2004–2008 [66].

Item	2004	2005	2006	2007	2008	Total
Total primary energy production (quadrillion Btu)	3.774	3.604	3.580	3.518	3.791	18.267
Total primary energy consumption (quadrillion Btu)	2.261	2.289	2.365	2.325	2.452	11.692
Total oil production (thousand barrels/day)	861.810	725.774	731.716	704.596	727.838	3757.734
Total petroleum consumption (thousand barrels/day)	508.638	521.849	534.414	544.937	536	2645.838
Emission CO_2 from petroleum consumption (million metric tons)	69.473	71.929	71.947	72.699	72.161	358.209
Total biofuels production (thousand barrels/day)	0	0	1.100	2.500	4.500	8.1
To biofuels consumption (thousand barrels/day)	0	0	0.2	0.7	0.9	1.8

substantial amount of lignocellulosic agriculture waste, especially oil palm biomass, is generated in Malaysia. The waste generated from the oil palm industry has the potential to be further processed into bioethanol through biorefinery [20]. Recently, Japan's Mitsui Engineering & Shipbuilding Co. Ltd. (MES) announced plans to introduce a plant in Malaysia for producing bioethanol from oil palm biomass. Mitsui planned to build a pilot plant in 2008 and to commence testing and trial operation by 2010. If found feasible, Mitsui will collaborate with a local company from the oil palm sector to invest RM10.8 million in a pilot plant for commercial production of bioethanol. They are currently conducting fieldwork to optimize the productivity of bioethanol from oil palm trunks, oil palm fronds, empty fruit bunches and palm kernel shells [11,70]. The successful implementation of this project will spur the biofuel industry and develop a new and first base SGB plant in Malaysia.

Of late, the setting up of lignocellulosic biorefineries has been initiated all around the world. Production of SGB is the major aim of these biorefineries. A basic biorefinery is a capital-intensive project and is based on just one conversion technology to produce various chemicals. The limitations increase the cost of outputs (or products) generated from such biorefineries. To save cost, an integrated biorefinery is more advanced as it facilitates the diversification of feedstocks and products, consists of several conversion technologies and provides its own power [71]. In Malaysia, there is a sizable paper and pulp industry. Instead of solely producing pulp and paper, it is possible to integrate with other processes to enable competitive advantages. For instance, Suntana et al. [72] and Mendes et al. [73] have studied the potential of integrating large bio-energy systems, such as pulp and paper mills in Indonesia and Portugal. The results show that such integration will change the industry through additional products, such as biofuel or biomaterials, and increased profits.

Malaysia is the main exporter of palm oil in the world, which produces a large amount of lignocellulosic waste. Converting these unwanted wastes into RE, such as bioethanol, is definitely a strategic move for Malaysia to become a self-sufficient country in the future. As Malaysia has no experience with the production of SGB, studying the experiences of ethanol producer countries or the work of ethanol researchers will provide some ideas for a future path. A few important policy and measures are recommended to promote second-generation bioethanol as a substitute to fossil fuels. The paper written by Svrk and Elder (2009) [76] suggest the following measures [4]:

I. Trade liberalization by opening the agricultural markets.
II. Investment in agricultural research and extension systems to translate sciences into technology.
III. Use of renewable sources of energy in farming.
IV. Including input use levels in the bioethanol certification system.
V. Promoting resource-conserving technologies.
VI. Channeling subsidies.

The Brazilian government's policies include the following measures [12,74]:

I. Government and private grants funding in R&D.
II. Promoting the use of flexible fuel vehicles (FFVs).
III. Implementing a carbon-based fuel tax policy.
IV. Establishing cooperation between the government and private companies to build a systematic infrastructure to collect, transport and store cellulosic feedstock.

Others measures include the following [31]:

I. Credit guarantee scheme for SGB related loan.
II. Launching an awareness program on SGB.
III. Inclusions of externalities (choice of technology imposes a certain cost on society and the environment).

8. Conclusion

Throughout the whole studies about the issues and concerns of Malaysia energy and fuel industry, Malaysia significantly has a great potential to develop second-generation bioethanol (SGB). Although there is no national strategy made for or priority given to bioethanol development as compared to biodiesel in Malaysia at present, its abundant availability feedstock biomass provides a good justification for Malaysia to develop this new renewable energy sources. The data and analysis on current energy status in Malaysia through the features like energy security, economic consideration and climate changes have proven that Malaysia needs a liquid bio-fuel like bioethanol to substitute fossil fuels in transportation sector. As a result, Malaysia needs to put more effort on ethanol development with equally as biodiesel to avoid the coming energy crisis problem.

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